MANUFACTURING CFRP SANDWICH PARTS USING WET MOULDING

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Abstract
Fibre-reinforced composites are introduced into fabricating car bodies in mass production recently. In order to comply with the increased requirements of automotive manufacturing, production cycle times and production costs need to be reduced. A promising approach is currently under development at BMW Group, involving CFRP sandwich parts manufactured by wet moulding and prepreg pressing. The substitution of a sandwich component for a modular shell construction results in a reduction of the overall production steps and a lesser effort for tooling costs, joining technology, assembly and logistics. This contribution aims at presenting the already acquired knowledge about the process. This includes the influence of core compression and temperature development in the sandwich construction on the characteristics of the face sheets. Additionally, the fabrication of the semi-finished goods is examined individually. Two types of material are utilised to pre-assemble the face sheets: a combination of non-crimp fabric and liquid resin as used in wet moulding and prepregs, which derive from the MAI Autopreg project using filament winding. Due to cost efficiency in mass production, milling of the core has to be replaced by alternate technologies. Recent investigations demonstrate the feasibility of manufacturing near net shape sandwich cores using thermoforming.

1. Introduction

Due to a transition to lightweight design in the automotive industry in recent years, the usage of fibre composites for manufacturing car body parts is increasing. As expected, the applied production methods are those with a high throughput, i.e. moulding technologies. Compression moulding methods such as SMC or BMC already provide an annually throughput [1] that fulfils the requirements of automotive mass production. Those techniques are well-established and widely used for manufacturing mainly short fibre reinforced parts for private cars and commercial trucks [2]. As of late, continuous fibre reinforced polymers, especially carbon fibre reinforced, are introduced to mass production of car body parts. This results in upscaling well-established liquid composite moulding (LCM) methods in order to comply with the increased requirements of automotive manufacturing. Therefore, a general improvement of various steps along the process chain is required, including a reduction of production costs and shortened production cycle times [3].

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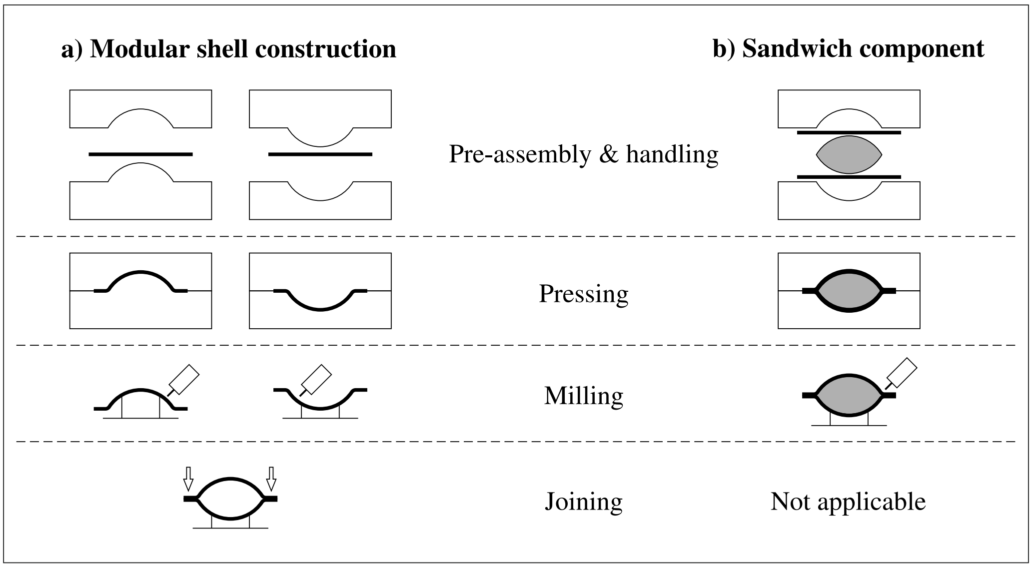

Figure 1. Production steps for a modular shell construction (a) and a sandwich component (b).

A promising approach is currently under development at BMW Group, which involves investigating wet moulding [4] and prepreg pressing for manufacturing car body parts made from CFRP sandwich structures. A sandwich part is, by definition, a composite material consisting of high-tensile and rigid top layers and a shear rigid core [5]. Sandwich parts are widely used in the transportation and shipping industry [6]. The research approach discussed in this paper is based on the idea that by substituting a sandwich component for a modular shell construction, various production steps can be shortened or even omitted [4]. The effort for tooling costs, joining technology, assembly and logistics for fabricating a sandwich part in a single production step is lower compared with the effort for manufacturing single shell parts, as shown in Fig. 1. Furthermore, utilising a sandwich core as a carrier for inserts at force transmission points [7] or other functional elements is an efficient approach to increase the component complexity. These are typical characteristics for many of the various LCM methods, e.g. resin transfer moulding (RTM). The additional benefits of wet moulded sandwich parts stem from the monolithic wet moulding process: low tooling costs, a short cycle time and a highly automatable process. The usage of pressing technology for manufacturing composite sandwich parts has been discussed before [8–10], however, the application of honeycomb cores, wave cores or other only partially supporting cores is not suitable for complex car body parts. Different types of cores with a homogeneous supporting effect are listed in [11, 12], including foamed materials. This contribution focusses on the application of closed-cell foams made from plastics.

2. Materials and methods

2.1. Materials

There are two types of material that are used for fabricating the sheet layers: Firstly, a combination of non-crimp fabric (NCF) made from 50K carbon fibre rovings (SGL Automotive Carbon Fibers GmbH & Co. KG, München, Germany) and a three-component epoxy resin system (Hexion Inc., Columbus, USA). Those semi-finished goods originate from the monolithic wet moulding process used for manufacturing the Carbon Core of the BMW 7 Series. Secondly, sheet layers are utilized that are composed of prepreg sheets fabricated via filament winding (Voith Composites GmbH & Co. KG, Garching b. München, Germany). This technology, including a moulding method called carbon preimpregnated pressforming (CPP) is investigated separately in the MAI Autopreg project [3]. Applying semi-finished

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goods consisting of a B-stage resin system that stem from filament winding in a pressing process has been known for a long time [13].

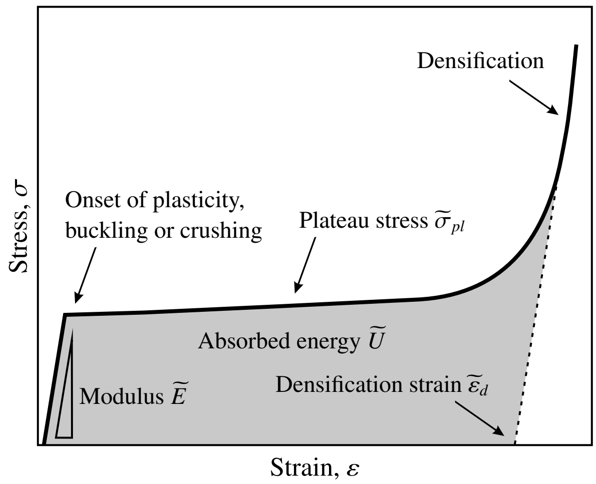

Figure 2. Cellular solid: stress-strain curve [14].

The application of closed cell foams for manufacturing complex shaped sandwich parts offers the opportunity to exploit a mechanical property of cellular solids. As shown in Fig. 2, a foam structure buckles at a nearly constant stress plateau after an initial linear-elastic phase [15]. Consequentially, a foam core provides a nearly stable counteracting force on the sheet layers for a foam compression between the onset of plasticity and the densification, resulting in a wide process window for wet moulding sandwich parts. This investigation deals with expanded polymethacrylimide (PMI-E, Evonik Industries AG, Essen, Germany) and expanded polyethylene terephthalate (PET-E, Airex AG, Sins, Switzerland). Detailed information about density and compressive strength are shown in Tab. 1. These foam materials are used to fabricate generic parts (sandwich plates) as well as prototype parts. The main difference consists in the production method of the respective semi-finished good for the prototypes. While the PMI-E prototype core is milled from a larger block of raw material as it is characteristic of CFRP sandwich prototypes or small batch series, the PET-E core is manufactured using a thermoforming method. The raw material is roughly cut into shape, heated and subsequently converted into a near net shape core using a pressing tool. This results in an inhomogeneous density of the PET-E prototype cores.

2.2. Methods

In order to substitute a sandwich part for a modular shell construction, two main topics need to be investigated: Firstly, the moulding method for sandwich parts itself and, secondly, the overall process chain, especially before the pressing. Therefore, the current investigation is split into fabricating generic sandwich plates (sec. 3.1) and prototype parts (sec. 3.2). The former offers the opportunity to yield detailed information about the method in a cost-efficient way, the later is used to test and optimise an automated preparation, assembly and handling of sandwich semi-finished goods. Furthermore, the utilisation of thermoformed foam cores can be tested in a real-case scenario. The moulding method for CFRP sandwich derives from monolithic wet moulding. As stated in [4], there are a couple of additional steps in comparison to the monolithic method during the preparation: preparation and handling of three components (two textiles and a core), double resin application and the pre-assembly. Obviously, the resin application is omitted when prepreg sheet layers are used. For both types of sheet layer materials, it is important to note that those additional steps should not prolong the overall production cycle. Therefore, preparation and assembly must remain in secondary processing time while the actual pressing cycle defines the primary processing time.

Table 1. Overview: plastic foam materials [16, 17]

Material	Name	Density (kg/m^3)	Compr. strength (MPa)
PMI-E	Rohacell® 71 IG-F	75	1.5
PMI-E	Rohacell® 110 IG-F	110	3.0
PET-E	Airex® T10.100	100	1.5

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3. Results and Discussion

3.1. Generic sandwich parts

In the following, two distinctive features of the sandwich moulding method are presented, namely, the temperature profile obtained from fabricating sandwich panels and the influence of the core compression on the thickness of the sheet layers.

3.1.1. Temperature profile

Fig. 3 shows temperature data of the upper half of a sandwich panel, consisting of 6 layers of NCF, epoxy resin and 2 layers of Rohacell® 71 IG-F, each with a thickness of 5 mm. Consequently, the thermocouple T_8 is positioned exactly in the middle of the sandwich. T_1-T_7 are thermocouples as well, while T_S is a tool mounted sensor providing data for the surface temperature of the tool. The first vertical line on the left, ①, marks the point of time when the initial contact between the hot tool and the resin occurs, ② marks the point of time when the tool is closed and the forming is completed. The data sets T_1-T_6 overshoot the threshold of 130 °C, i.e. the tool temperature, before they eventually converge.

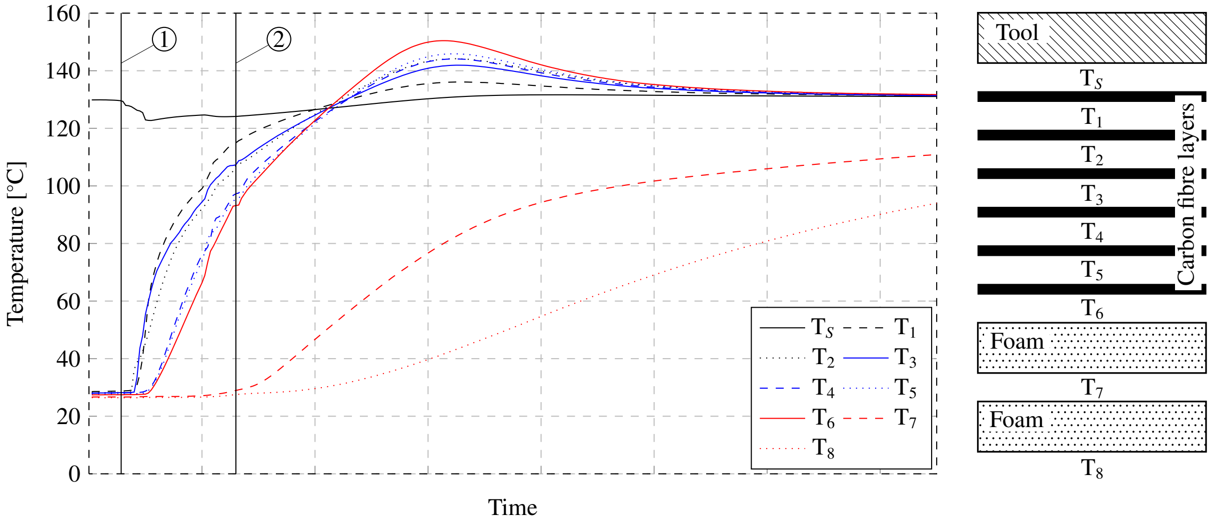

Figure 3. Temperature profile of the upper half of a sandwich specimen fabricated using wet moulding.

Comparing T_1-T_6, it is obvious that the thermocouple with the biggest distance to the tool wall overshoots the most. This is indicative of the exothermic reaction of the epoxy resin. After an initial supply of heat to accelerate the curing, the tool wall functions as a heat sink and drains the excess energy when the resin temperature passes the threshold. Due to the low thermal conductivity of plastic foams in comparison to metals [18], the heat flow on the inside of the sheet layer is significantly lower than on the outside. Despite the amount of energy inside the sandwich, the temperature of the core is delayed in time compared to the textile layers and does not reach the threshold level before the end of the process - which is not shown in Fig. 3. Most notably, the heating of the core is delayed so much, that the forming of the sandwich part is completed and the epoxy resin reaches form stability before the foam approaches its softening range.

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3.1.2. Core compression

Fig. 4 shows cross sections of sandwich panels made from Rohacell® 110 IG-F with a thickness of 20 mm and the same sheet layers used for the parts in the previous section. The main difference between the two parts is the compression of the foam when the tool is completely closed. For specimen a) the tool was configured for 0 % compression, hence the foam core functions as a second tool wall similar to monolithic wet moulding. The resulting mean thickness of the sheet layer is 1.95 mm. For specimen b), the foam was compressed to 75 % of the original thickness, i.e. 25 % strain. The graphs shown in [19] are indicative of an onset of buckling for PMI-E around 5 % strain and a densification at 70-75 % strain, therefore a compression of 25 % is well within the constant stress plateau (Fig. 2). Consequentially, the mean sheet layer thickness of specimen b) is 1.49 mm.

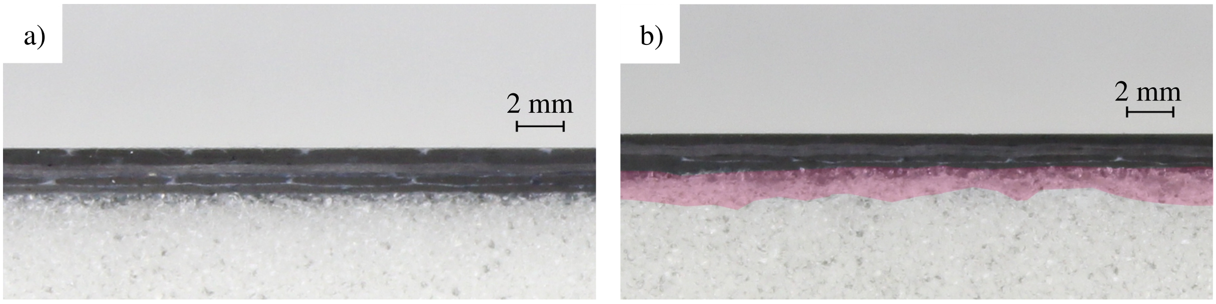

Figure 4. Generic parts: specimen a) with 0% compression and specimen b) with 25 % compression.

Highlighted with light red on the right, the area close to the boundary between fibre layers and foam is a mixture of crumbled foam cells and excess resin due the compaction of the textile layers. This characteristic is decribed in [15]: brittle foams like PMI-E tend to collapse by cell wall fracture, from the outside to the inside.

3.2. Sandwich prototypes

The prototype parts are used to test and optimise an automated production system for wet moulding CFRP sandwich parts. A selection is presented in the middle and on the right of Fig. 5. The automation includes the preparation steps mentioned in sec. 2.2: handling of all semi-finished goods, resin application if applicable and pre-assembly. The handling tools including grippers are connected to a robot which is the center of an automated production cell at an experimental stage.

Figure 5. Prototype parts: modular shell construction (a), sandwich part with a milled PMI-E core (b) and sandwich part with a thermoformed PET-E core (c).

Fig. 5 shows the technical feasibility of forming the sheet layers in a sandwich moulding process. Both foam materials provide a sufficient counteracting force to compact the textile layers. However, the sheet layers of both sandwich parts is thicker at the sidewalls (PMI-E: 2.7-2.9 mm, PET-E: 2.8-3.2 mm) than the nominal dimension of 2.5 mm. A possible reason for this behaviour might be an insufficient pressure normal to the sidewall. A possible solution could be an oversizing of the foam core at the lateral faces. Furthermore, the bright white parts of specimen c) are the compacted foam cells caused by the thermoforming process. In contrast to the brittle PMI-E core of the generic parts, no excess resin intrudes the cells because elastomeric foams like PET-E fail by buckling of the cell edges without opening up [15].

4. Conclusion

In summary, the results presented in section 3 demonstrate the feasibility of manufacturing CFRP sandwich parts in a fully automated wet moulding or prepreg pressing process. In detail,

- the sandwich moulding method is feasible with both types of sheet layers, prepregs and NCF and epoxy resin,
- the process stability of the utilized PMI-E and PET-E cores is evident,
- the fully automated process is functional at an experimental stage and needs to be optimised further for a series application.

Therefore, in terms of production technology, it is possible to substitute a sandwich part for a modular shell construction while maintaining a highly automatable method with a high annual output.

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